



... for a brighter future

Testing USABC Deliverables/Benchmarking

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**Office of Vehicle
Technologies**



Overview

Timeline

- Test Facility Commissioned: 1976
- End: Open - this is an ongoing activity to test/validate/document battery performance as the technology continues to evolve and mature

Budget

- Total project funding: \$1.4M/yr from DOE
- FY08: \$1.4M
- FY09: \$1.2M

Objectives

- To provide DOE with an independent assessment of DOE contract deliverables
- To benchmark commercial battery technology developments

Collaborations

- Idaho National Laboratory, Sandia National Laboratories, Lawrence Berkeley National Laboratory
- USABC

Testing USABC Deliverables/Benchmarking

■ Purpose of Work

- To provide DOE, USABC, and battery developers with reliable, independent, and unbiased performance evaluations of cells, modules, and battery packs
- To benchmark battery technologies which were not developed with DOE funding to ascertain their level of maturity. This will help DOE use its limited resources to provide support to emerging technologies for the maximum benefit
- To identify promising technologies
- To perform battery performance and life evaluations on FreedomCAR Program contract deliverables

Barriers Addressed and Approach

■ Barriers

- Develop and apply standardized measures to gauge battery performance and life

■ Approach

- Benchmarking
 - *Use the FreedomCAR test protocols to evaluate battery performance and life (calendar and cycle)*
 - *Use accelerated screening protocols to evaluate battery performance and cycle life*
- USABC Contract Deliverables
 - *Use the FreedomCAR test protocols to evaluate battery performance and life (calendar and cycle)*
- Analyze data for trends and model creation
 - *Project life without exhausting battery under test*
- Participate in new manual creation and validation
 - *FY08, Battery Life Estimation Manual and Plug-in Hybrid Battery Test Manual*

Approach (cont'd)

■ Approach

- The test protocols used are standardized and unbiased, allowing for a direct comparison of battery performance within a given technology and across technologies
- The performance of small cells can be compared to that of large cells, modules and full-scale battery packs by using a battery-scaling factor (BSF)
 - *BSF: for a particular cell or module design, an integer which is the minimum number of cells or modules expected to be required to meet all the FreedomCAR performance and life goals, assuming a 30% power margin at the beginning of life*
 - *Usually, the BSF is calculated from the initial RPT data from the HPPC-L test, using the plot of available energy vs. power*
- Test manuals are available on the world-wide web:
http://www.uscar.org/guest/article_view.php?articles_id=86

Performance Measures and Technical Results

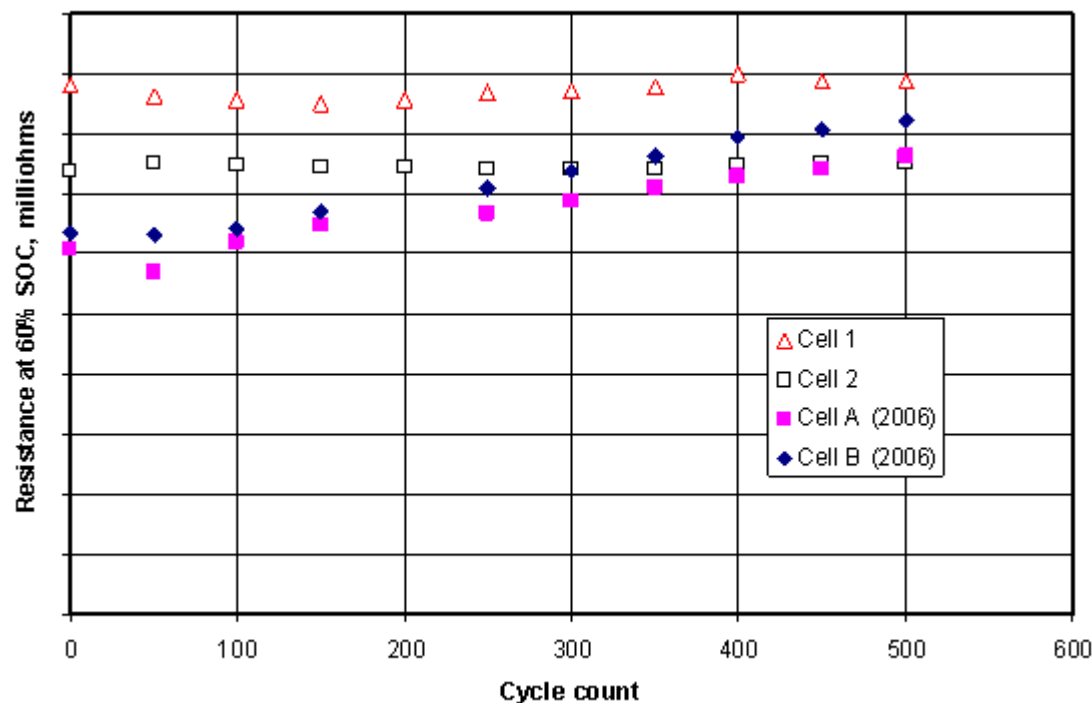
- Testing of deliverables is an open-ended effort. Each year, milestones related to the expected deliverables are developed
- In FY08, the milestones were
 - HEV batteries: Test battery technologies from A123 Systems, Johnson Controls-SAFT
 - *Testing still in progress*
 - PHEV: Validate the new test manual using prototype cells. Provide comments to Idaho National Laboratory to refine the test manual. Test contract deliverables from Johnson Controls-SAFT
 - *Testing still in progress*
 - Benchmark battery technologies for vehicle applications
 - *Test deliverables from SK Energy, G4 Synergetics, Mitsui Mining and Smelting, Samsung, Firefly Energy*

Accelerated Testing Protocols

- These protocols were designed to accrue many cycles on a battery quickly and to work on both high-energy and high-power cells
- Accelerated testing determines the performance stability of the battery in a short amount of time
- These protocols are not PHEV tests
- Testing protocol includes
 - Exact current levels depend on cell ratings
 - Characterization/Reference Performance Test (RPT) consists of constant-current capacity and HPPC at the low current level at 30°C
 - Constant-current cycle at 40°C
 - Every 50 cycles perform an RPT at 30°C

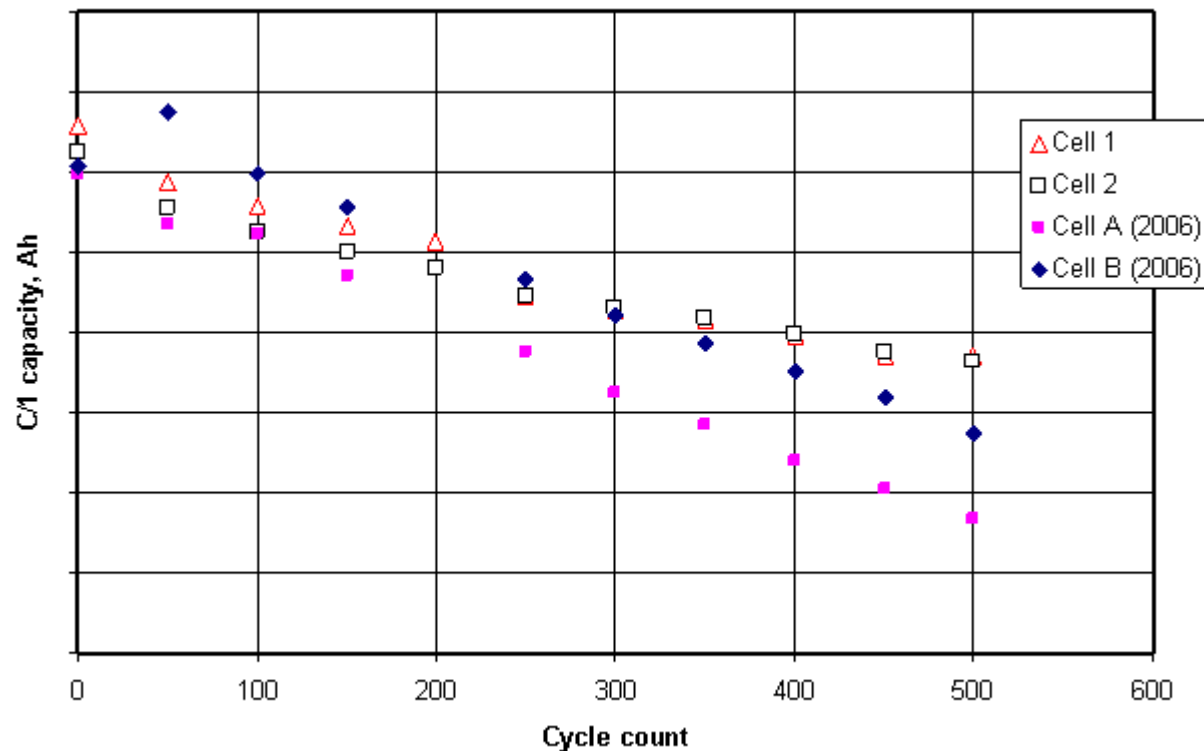
Example Test Results From High-Power Battery Using the Accelerated Protocols – Cell Resistance vs. Time

- Cycle life test consisted of 0 to 100% charge/discharges at the 1C rate at 40°C
- Battery successfully completed 500 cycles
- Rel. resistance values are from HPPC-L test using the 5C/3.75C rates
- Cell resistance was fairly constant with time
- Comparison with earlier test results show improvements in the technology



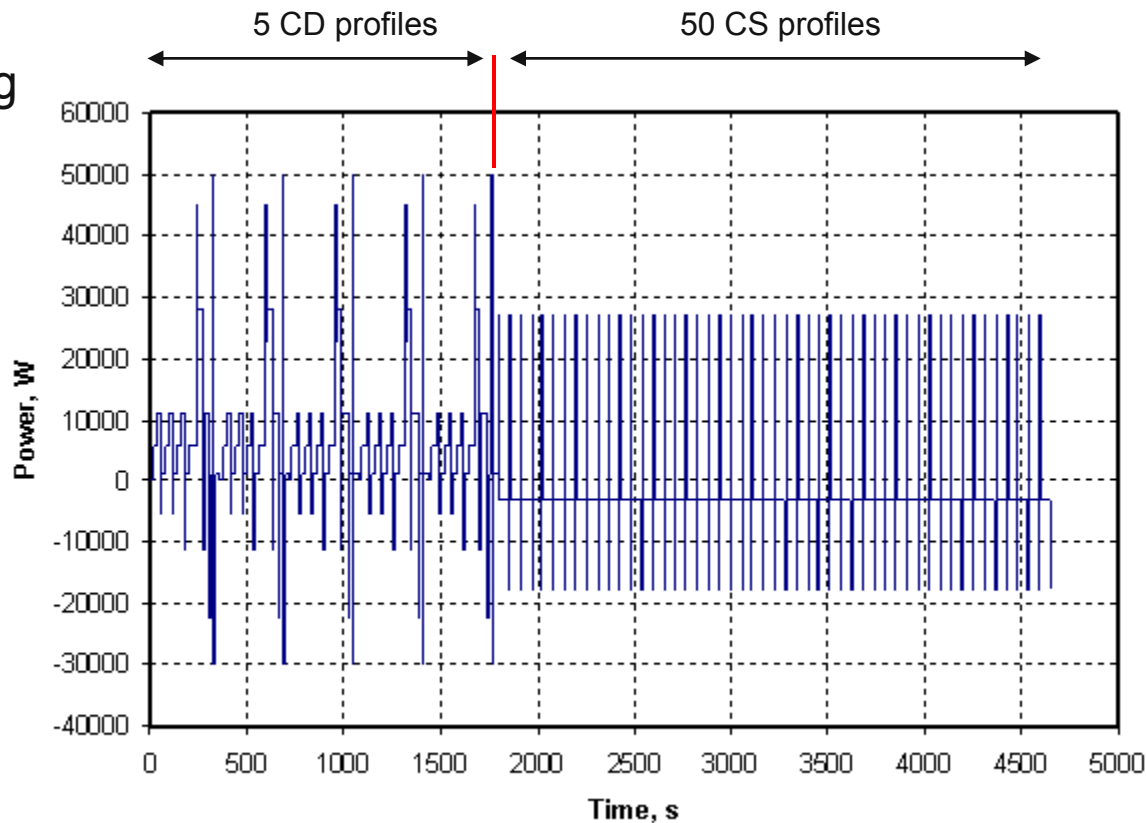
Example Test Results From High-Power Battery Using the Accelerated Protocols – Cell Capacity vs. Cycle Count

- Cell C/1 capacity decreases linearly with time
- Rate of decrease is less when compared to the results from 2006



PHEV Manual Verification -- Cell Testing

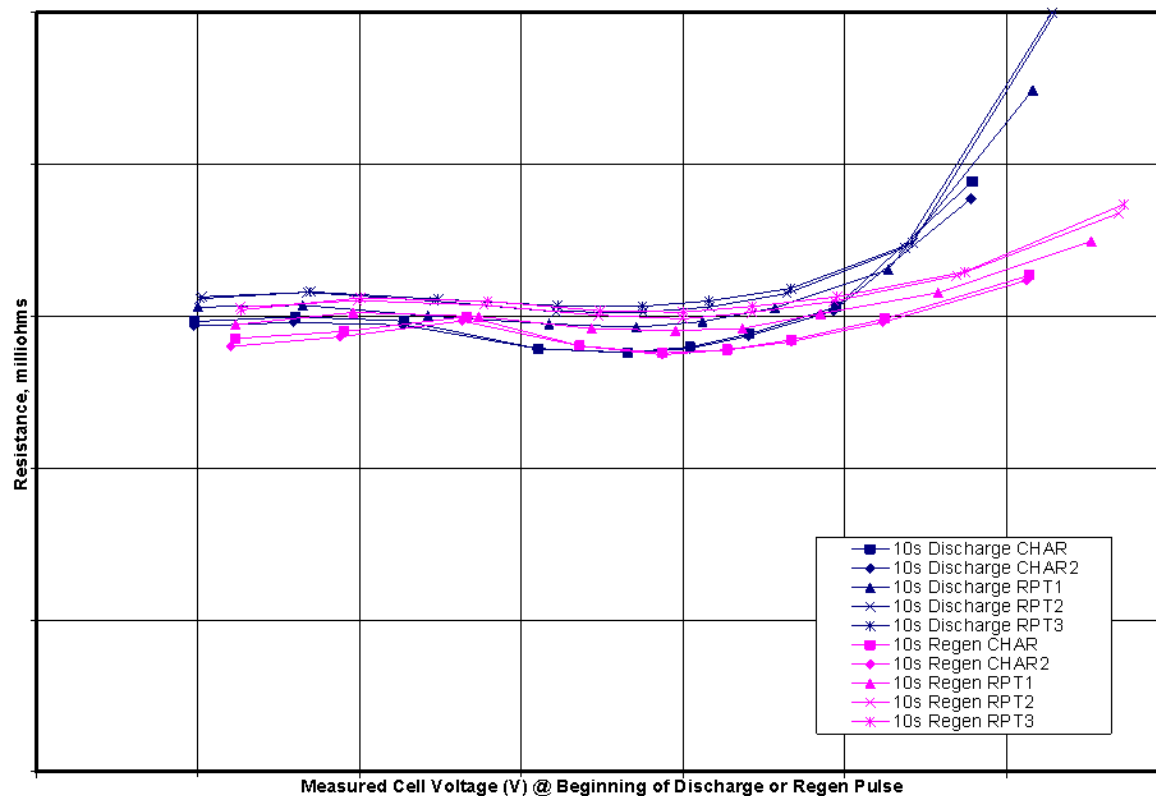
- How does the SOC for cycling impact cell life?
- Cells were cycled at 30°C using a combined charge-depleting (CD)/charge-sustaining (CS) profile
- CS portion was performed at two states of charge (SOCs), 60% and 30%, representing HEV and PHEV modes of operation
- 60% SOC = ~3 CD profiles
- 30% SOC = ~5 CD profiles



Combined cycle profile

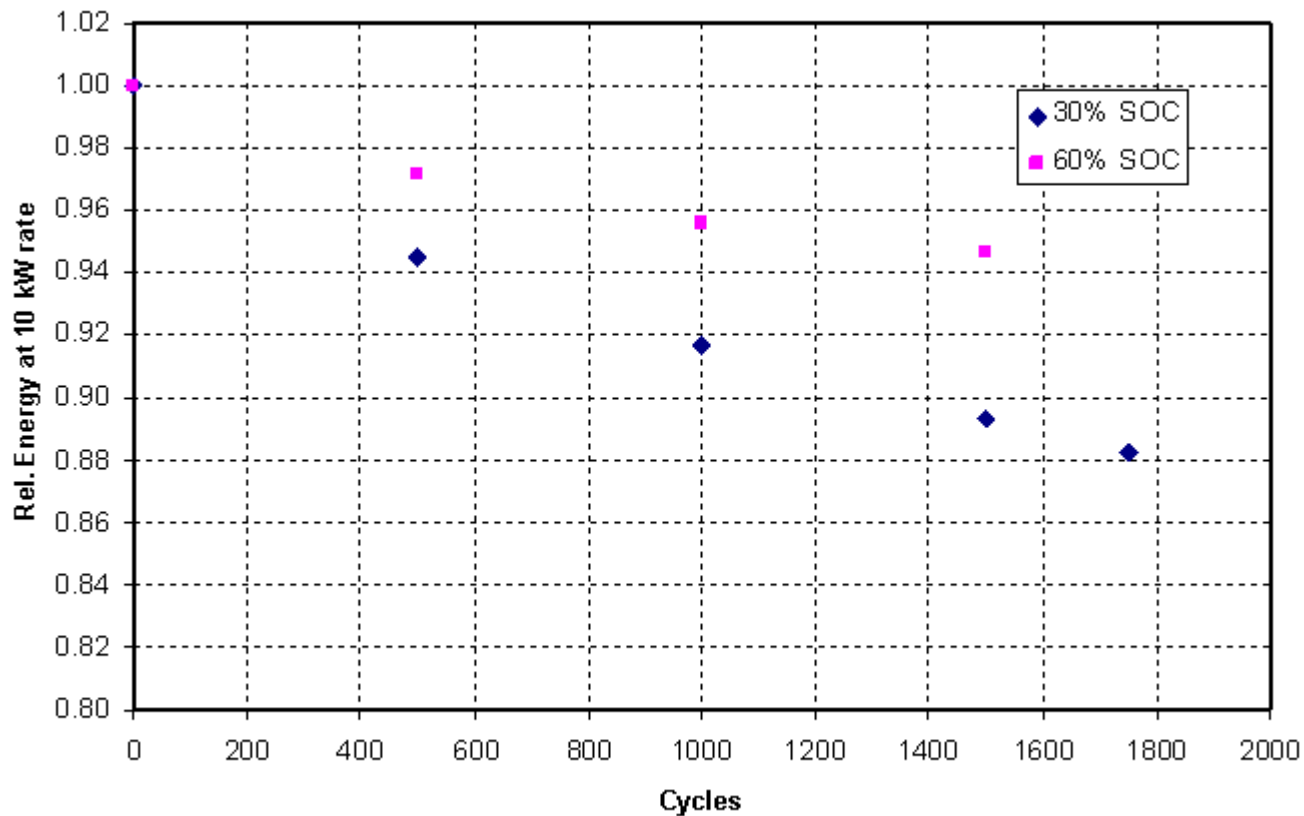
Example Results from PHEV Cell Testing

- RPTs were performed every 500 combined cycles
 - HPPC and C/1 capacity measurements
- Cycling does not appear to have a large effect on cell resistance



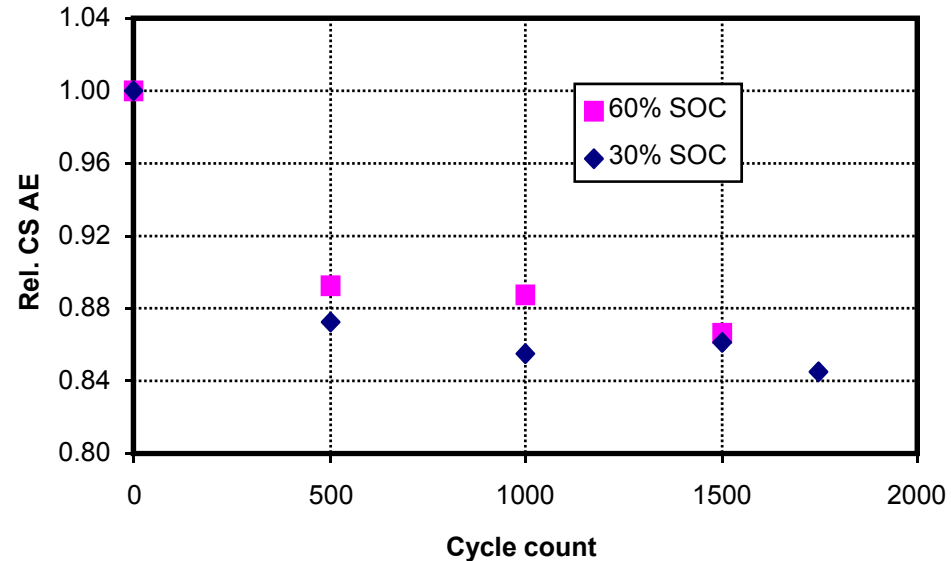
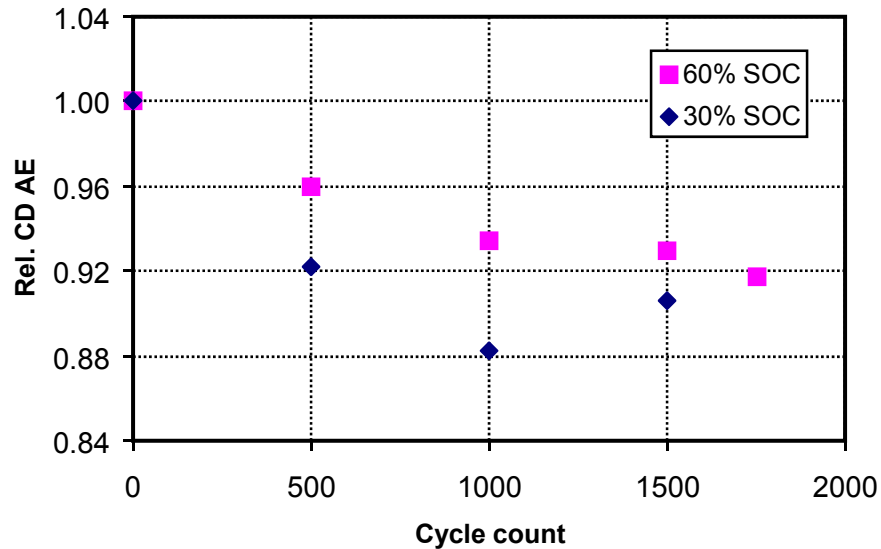
Effect of Cycling and of SOC on Cell Energy

- Energy at the 10-kW rate fades with time and SOC



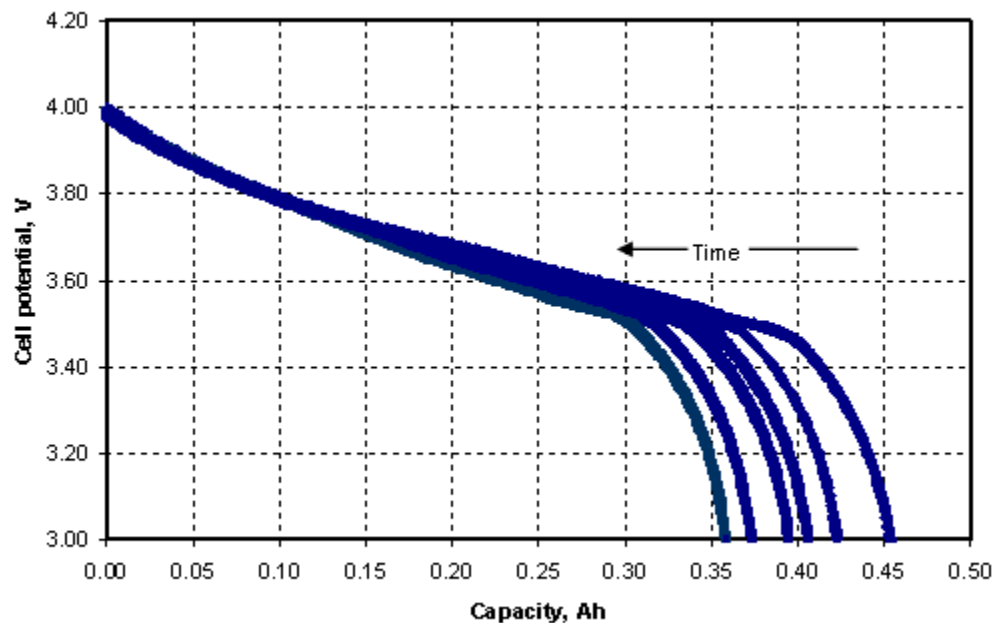
SOC Effect Is Seen in CD Energy

- SOC-dependent fade is seen in the CD available energy
- Fade in the CS available energy is not sensitive to SOC



Data Analysis Technique Arising From Cell Testing – dV/dQ

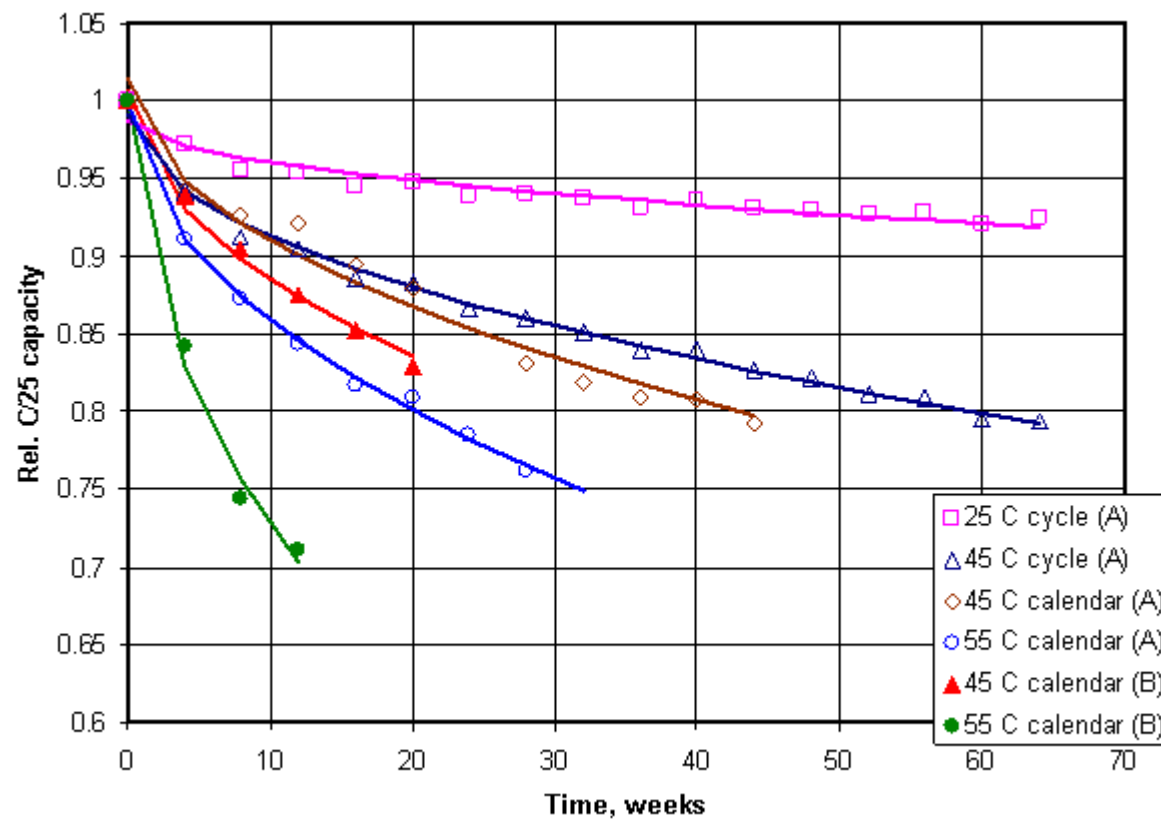
- Pouch cells were from the ATD program
- Cell chemistry: $\text{Li}_{1.07}(\text{Mn}_{1/3}\text{Ni}_{1/3}\text{Co}_{1/3})_{0.95}\text{O}_2$ | 1.2 M LiPF₆ in EC:EMC (3:7 by wt) | MCMB
- In collaboration with INL,^{*} cells were tested for cycle and calendar life at 60% SOC at 25°C (cycle), 45°C (cycle + calendar), and 55°C. They were characterized in terms of C/25 capacity, among other parameters, at 4-week intervals



^{*}J. P. Christophersen
and C. D. Ho

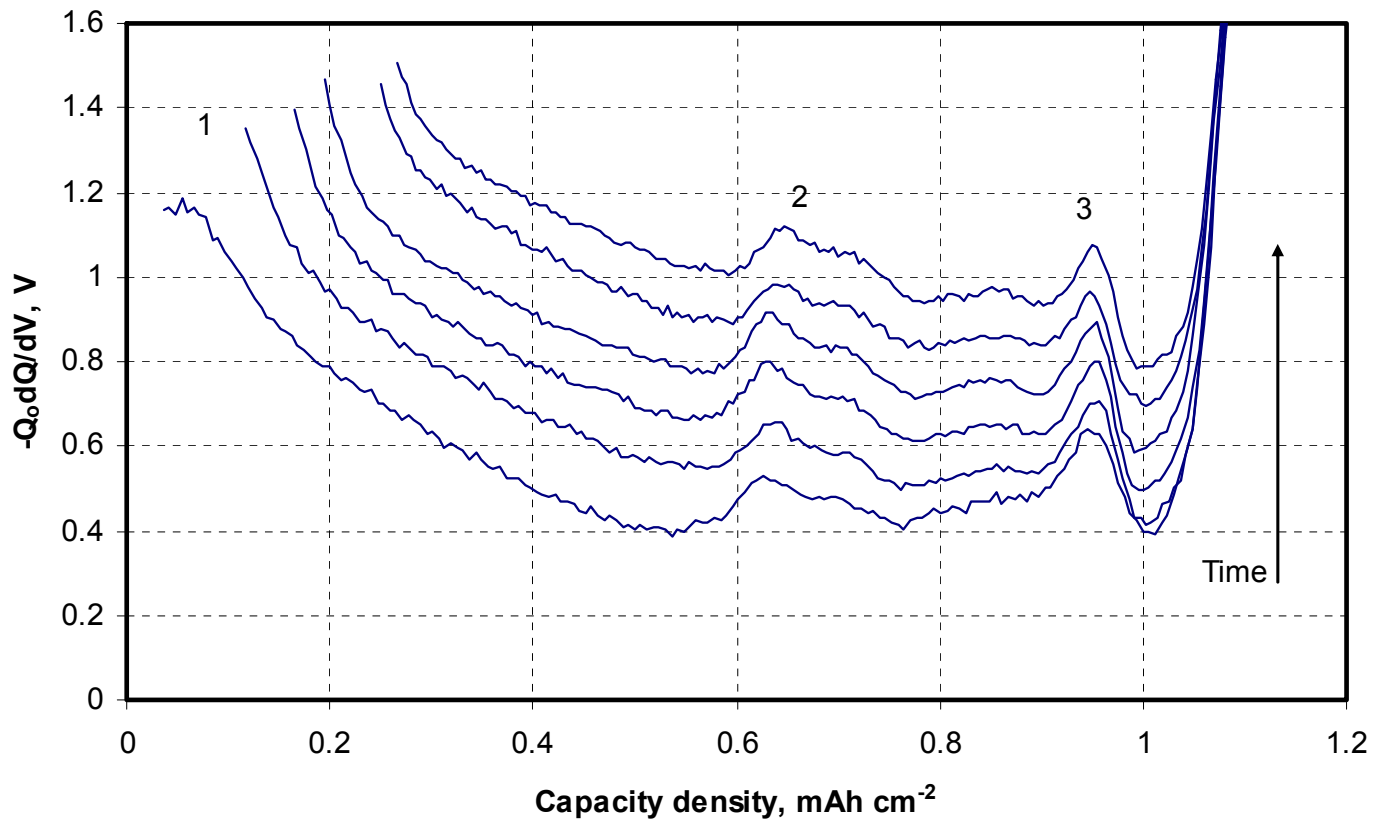
C/25 Capacity Declines With Time

- C/25 capacity in all cases is proportional with $t^{1/2}$



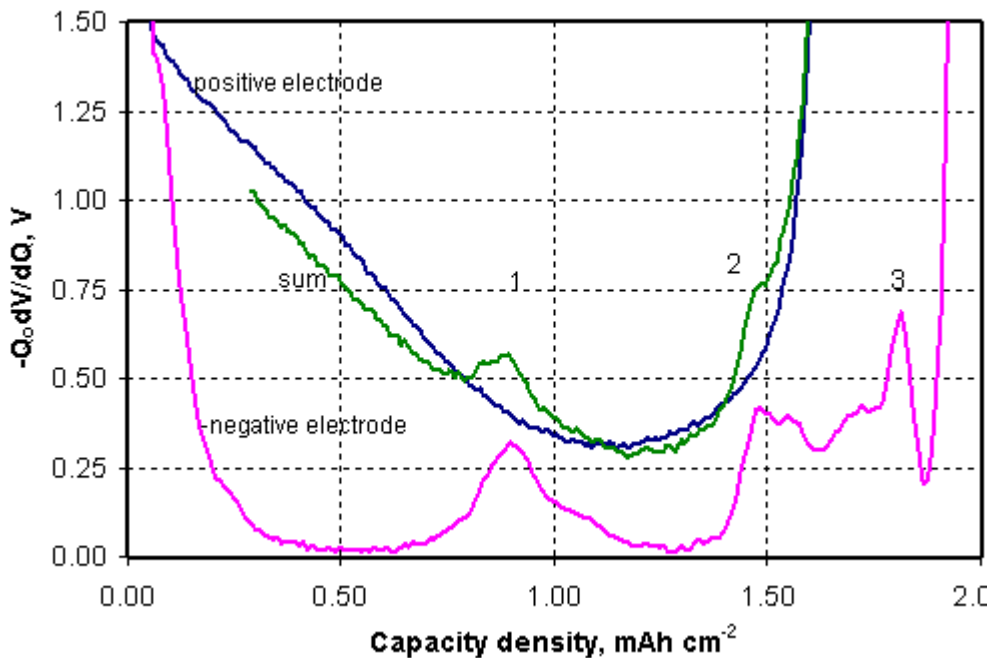
The dV/dQ Curves Change with Time

- Peak pattern changes with time



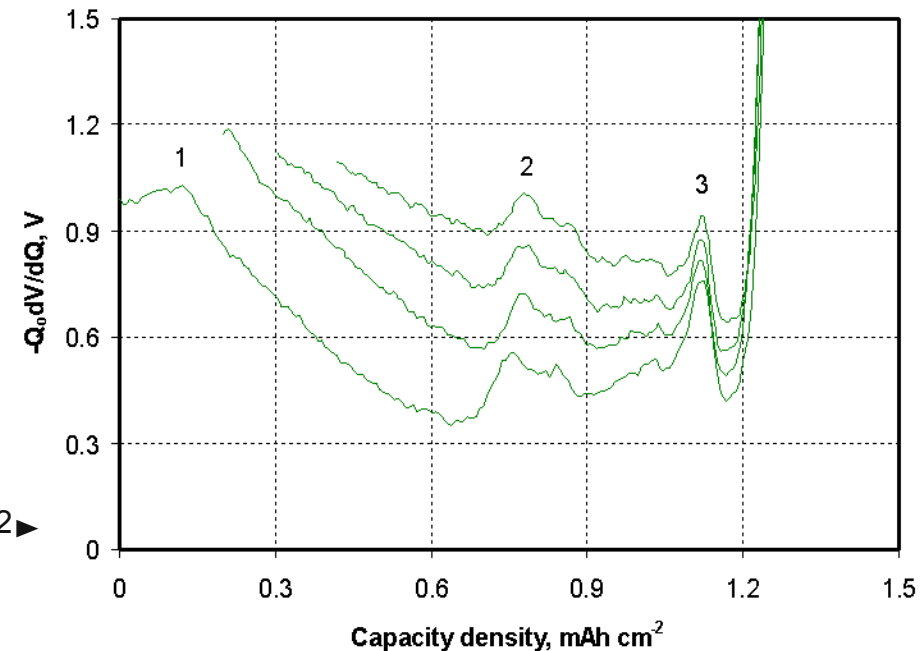
Modeling Was Used to Understand Source of Peak Pattern Change

- dV/dQ curves from half-cell data,* the dV/dQ peak patterns were calculated, allowing the active portions of the electrodes to shift relative to the other



Shift of 0.5 to 0.875 mAh/cm^2 ►

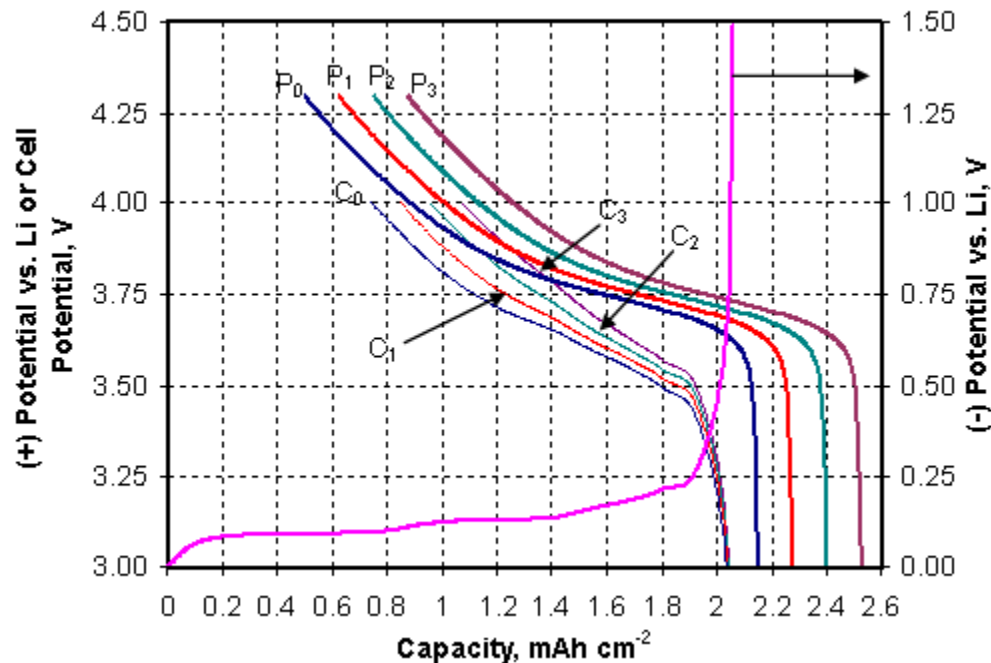
◀ No shift



*Half-cell data from D. P. Abraham

Apparent Shift of Positive Electrode Relative to Negative Affects Cell Capacity

- Increases in shift decreases cell capacity, while maintaining the 3 to 4 V cell voltage range
- Probable cause is side reactions at the negative electrode, which consume Li capacity and block the high-Li-activity portions of the electrode from being used in the charge/discharge reactions
- This process was also seen in Gen2 cells (NCA cathode and MAG10 anode)



Activities for Next Fiscal Year

- Continue testing HEV contract deliverables
- Start testing PHEV contract deliverables
- Continue acquiring and benchmarking batteries from non-DOE sources
- Aid in refining standardized test protocols
- Upgrade and expand test capabilities to handle increase in deliverables (due to new PHEV program)

Summary

- Provide a valuable, independent capability to validate performance and life of advanced battery technologies
- Tested many different types of batteries using standard and accelerated protocols and provided fair comparisons between them (apples-to-apples)
- Some of the results indicated that unusual resistance increase/performance decrease mechanisms were present
- We continue to help DOE benchmark battery technology to learn its state of maturity
- Identified that aging mechanisms of different battery technologies are different
- Accelerated aging can be used to predict cell and battery life

Acknowledgment

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